Elevated biomass production in burned natural grasslands in southern India

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Abstract

Aspects related to community metabolism such as biomass production, turnover rate and time, and disappearance of the above-ground, below-ground and litter components were compared in burned and unburned sites. System-transfer studies of above-ground and below-ground components are also documented. The net primary production of the Kundah grasslands was very high (range 5294–6962 g/m^2/yr). The biomass of the community in different compartments, *viz.* grasses, legumes and "other species", varied considerably over the period of observation. Burning decreased total above-ground biomass in the early stages, but significantly improved biomass values in later stages. At the unburned site, however, the above-ground biomass remained more-or-less static. The below-ground biomass, unlike its above-ground counterpart, was not significantly altered by fire. Litter biomass steadily increased after a burn but remained static in the unburned site. Turnover rate increased in the burned site and turnover time was reduced.

Introduction

In most grassland communities, fire has been a disturbance factor since the origin of climate on earth. The historical prevalence of fire in grasslands has been well documented (Humphery 1962; Kirsh and Kruse 1972; Seevers *et al.* 1973). Fire is believed to have shaped and maintained the grasslands and prairie savannas (Sauer 1950; Scifres 1980), and is recognised as a major factor influencing the development, maintenance and management of grasslands (Kucera and Koelling 1964; Daubenmire 1968; Anderson 1972; Rice and Parenti 1978).

Burning has a variety of effects on ecosystems; the structure, life-forms and overall species composition are influenced by burning. The biomass of grass, forbs and litter and the relative abundance of different life-forms are highly coupled with the burning cycle. Abrams *et al.* (1986) found that live biomass was greater on burned than unburned lowland sites. Although the role of fire in influencing vegetation is accepted as a primary ecological factor, the effects on soil, wildlife and surface hydrology are recognised as essential secondary influences.

In view of the size of the world's grasslands and their potential for food production, the study of their primary production and the factors limiting this are of particular importance. Production and compartment transfer studies provide an insight into the functional aspects of the community. Pandey and Singh (1985) suggested that system-level properties such as biomass and nutrient regeneration are better indicators of recovery than transient species composition. Biomass is the manifestation of net production. Since metabolic rates differ from species to species, their production potential also differs. Thus, in various communities, the constituent species attain their maximum biomass in different months (Ovington *et al.* 1963; Wiegert and Evans 1964; Malone 1968).

Fire alters the production of rangelands. Production of the post-fire community is influenced by season and intensity of fire, the composition and phenology of pre-burn species of the community and other environmental factors. Fire stimulates above-ground production, as do other factors such as light–moderate grazing, above

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normal precipitation and increased soil depth (Barnes *et al.* 1983). The development and execution of management plans for any landscape, whether deliberate burning is a component or not, require a knowledge of wildfire incidence and its effects. Our earlier studies proved that the decomposition rate and successional pattern of micoflora in unburned soils were uniform (Senthilkumar *et al.* 1992; 1993a; 1993b) and burned savanna grasslands showed increased VAM fungal abundance and soil nutrient status (Senthilkumar *et al.* 1995). We found increased enzyme activity, VAM abundance in natural grasslands after fire (Senthilkumar *et al.* 1997a; 1997b), nutrient status, CO_2 evolution, N_2-fixing, P-solubilising microbes and high fungal density in some grasslands (Senthilkumar 1995). The present study attempts to characterise the effects of surface fire on the standing crop, primary productivity and litter output in Kundah grasslands from April 1992–April 1994. By applying the data, the potential of prescribed fire in the reserve management may be predicted.

Materials and methods

Study area

The study was carried out in the natural grasslands of Kundah plateau of Western Ghats, Tamil Nadu, southern India (11°13′N, 76°39′E; elevation 2150–2450 m). The grassland covers *ca.* 1000 ha adjacent to Shola forests, which are confined to moist and sheltered valleys. The temperature ranges from 4–29°C and the intensity of solar radiation is generally very high. The climatic data are shown in Figures 1a and 1b. During the second week of April 1992, a surface fire affected hundreds of hectares of the grassland, sparing a patch of about 60 ha off the Shola ingression. An alleged tribal fire in the first week of April 1993 burned a few hundred hectares in the area burned the year before. Enquiries revealed that the unburned patch of grassland usually escapes surface fire as it is isolated by a stream and adjoining Shola forest. However, both sites were burned in the summer months of 1991. Observations were made for 2 years from April 1992 on both the naturally isolated unburned patch and the burned area of grassland. Both sites were comparable in topography, soil type and vegetation.

Sample collection

Samples were collected during the last week of each month from April 1992–April 1994. The quadrat size of 50 × 50 cm was based on the species-area curve method. Quadrats were placed randomly in order to cover the site adequately. From each site, 5 monoliths were sampled each month. For estimating below-ground biomass, the monoliths were soaked in water for a few hours and then washed carefully to avoid any damage or loss of below-ground plant material. The samples were brought to the laboratory, hand-separated into 3 components, *viz.* grasses, legumes and "other species", and their above-ground (standing live and standing dead) and below-ground parts were separated. The litter component was also separated into the same 3 components in the field. The respective biomass values were determined after oven drying at 80°C for 48 h.

Primary production was measured by the short-term harvest method, in which the variations in plant biomass were estimated at monthly intervals throughout the study period. This technique is the most direct method for measuring community standing crop and its productivity and components (Schacht and Stubbendieck 1985).

The following aspects were studied in the present paper:

- standing crop biomass (standing live and dead parts, below-ground parts and litter);
- percentage contribution of the grasses, legumes and "other species" to total biomass;
- net primary production of the community;
- annual net production; and
- turnover rate and turnover time.

The net above-ground, below-ground and litter production were calculated by summing the positive increments in the biomass (Odum 1960; Singh and Yadava 1974; Sims and Singh 1978). Since the above-ground parts include standing live and standing dead components, the above-ground production was calculated by the summation of positive increments in the above-ground live biomass by species on successive sampling dates throughout the year, plus the positive increments in the standing dead biomass (Billore 1973; Billore and Mall 1977).

Dahlman and Kucera (1965) have used the term 'turnover' to designate the ratio of biomass which is built up in one year with respect to the

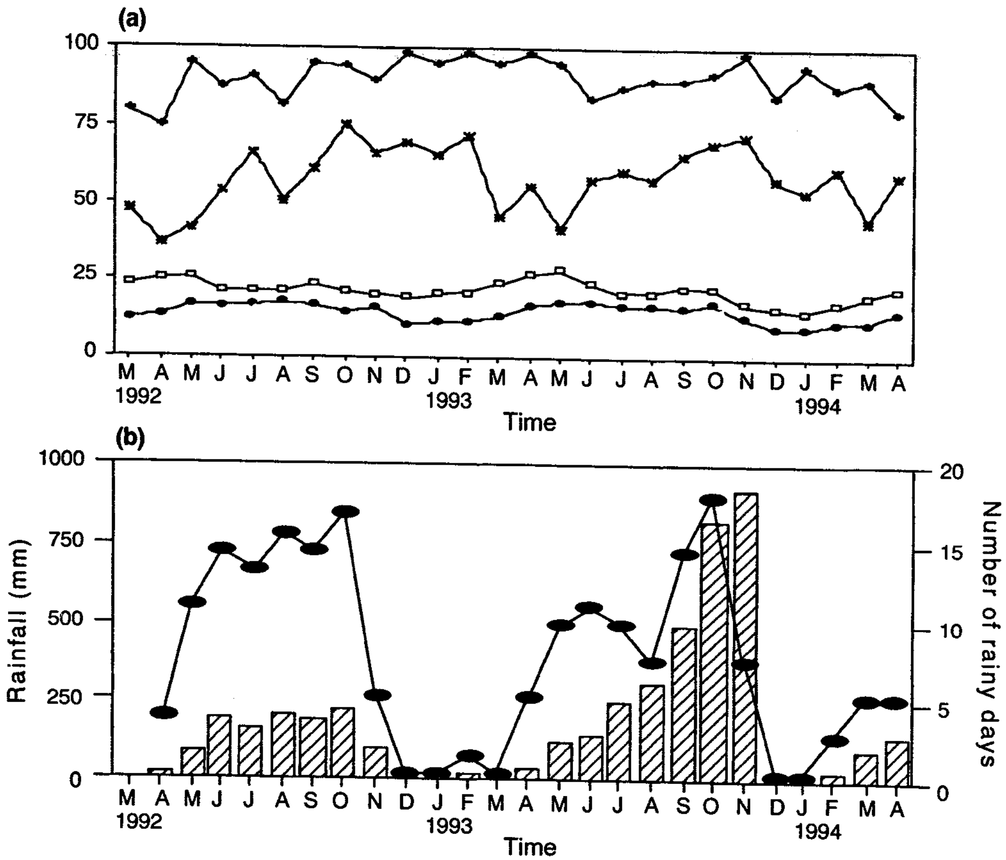

Figure 1(a). Maximum (—□—) and minimum (—●—) monthly temperatures (°C) and relative humidity (%) at 700 h (—✳—) and 1500 h (—✚—) during the study period.
Figure 1(b). Monthly rainfall (▨) and number of rainy days (—●—) during the study period.

maximum or peak biomass value. Turnover rate is a useful measure for comparing the exchange rates between different compartments (Odum 1983). The turnover rate of biomass was calculated using the following formula:

$$\text{Turnover rate} = \frac{\text{Net primary production}}{\text{Maximum biomass}}$$

Turnover time was calculated by reversing the turnover rate calculation (Odum 1960).

'System-transfer function' is an expression of the amounts of inputs and outputs among the compartment blocks of any ecosystem. Grodens (1963) regarded it as the quantity by which the system block multiplies the input to generate the output. It reflects the orientation of the functioning of an ecosystem in space and time (Sims and Singh 1971). To study the system-transfer functions, below-ground and litter disappearance (BGD and LD) were calculated using the following expressions (Singh *et al.* 1979):

BGD = Initial biomass of below-ground parts + below-ground production − final biomass of below-ground parts; and

LD = Initial biomass of litter + litter production − final biomass of litter.

The sum of values obtained for BGD and LD yielded total disappearance (TD). All values were calculated separately for the whole year. Models were prepared to show accumulation by different compartments for grasses, legumes and "other species". For all components, the above-ground, below-ground and litter parts were dealt with separately. It is considered that, for every gram of net primary production, the material used up in respiration was 0.3 g (Odum 1971). Then, Gross primary production = Total net primary production + material lost in respiration.

Statistical analysis

The data on biomass production such as above-ground, below-ground and litter production were subjected to statistical analysis to determine their significance ($P<0.05$). The Duncan's new multiple range test (DMRT) (Duncan 1951) was used to test the differences among replicate means. Correlations between certain edapho-climatic factors and biomass production of components were made by following Zar (1974).

Results

Above-ground (standing live and dead) parts

Figure 2 shows the fluctuations in above-ground biomass (AGB) of grasses, legumes and "other species" of unburned and burned sites. The monthly total above-ground biomass (TAGB) varied from 1445–2562 g/m^2 at the unburned site and 130–4361 g/m^2 at the burned site. At the burned site, TAGB values were lower during dry months, and progressively increased during the rainy and winter months. A similar trend was observed for the standing live and standing dead parts of grasses, legumes and "other species". Though burning seemed to decrease TAGB in the early stages, higher biomass values were obtained at later stages. At the unburned site, no such distinct trend was noticed for TAGB which remained more-or-less static. However, at this site, the grasses produced increased standing live biomass during the rainy season, which progressively decreased in the dry months. The standing dead grass biomass was inversely proportional to its standing live component. On the other hand, for legumes and "other species", both the live and dead AGB were generally higher during rainy months and decreased in dry months.

An overall observation of the data indicates that more than 85% of the AGB was contributed by grasses, of which *Cymbopogon polyneuros* was the dominant species. Interestingly, the percentage contribution of legumes improved by more than 2-fold at the burned site. At the unburned site, grass contribution to standing AGB ranged from 82–96%, with legumes comprising 0.7–7.6%. Standing live material ranged from 26% (April 92) to 72% (October 92) of the total standing biomass. At the burned site, grass contribution to standing AGB ranged from 69–91%, with legumes comprising 5.4–12.2%. Standing live material ranged from 45% (April 94) to 93% (May 93) of the total standing biomass. Above-ground production increased significantly ($P<0.05$) at the burned site in both years (Table 1).

Below-ground parts

The monthly variation in the below-ground biomass (BGB) at the study sites is shown in Figure 3. The BGB of the total community for both sites ranged between 647–1144 g/m^2, with grasses the dominant component. Unlike AGB, BGB was not significantly altered by fire (Table 1). Further, there were no seasonal influences on the BGB. Grasses contributed 80–97% to the BGB on both sites, with the lower figures occurring on the burned site during the last 5 months of the study.

Table 1. Mean monthly above-ground (AG), below-ground (BG) and litter production at the experimental sites during the 2 years of observation.

Year	Sites	AG	BG	Litter
			(g/m^2)	
1992–93	Unburned	179.9 a[1]	6.4 a	37.4 a
1992–93	Burned	316.7 b	38.1 a	72.5 ab
1993–94	Unburned	98.1 a	33.5 a	38.1 a
1993–94	Burned	361.2 b	35.4 a	115.4 b

[1]In a column, means followed by different letters are significantly different ($P<0.05$).

Litter

Monthly fluctuations in the litter biomass of the total community (Figure 3) varied between 12–1690 g/m^2. At the burned site, litter biomass accumulated steadily from the time of burning. No such trend was observed at the unburned site. Grasses accounted for more than 80% and 50% at unburned and burned sites, respectively. The fire event decreased grass litter while enhancing legume litter production markedly. Statistically significant ($P<0.05$) differences were found in litter components during the second year of observation. Contribution by grasses to litter ranged from 76–93% on the unburned site but

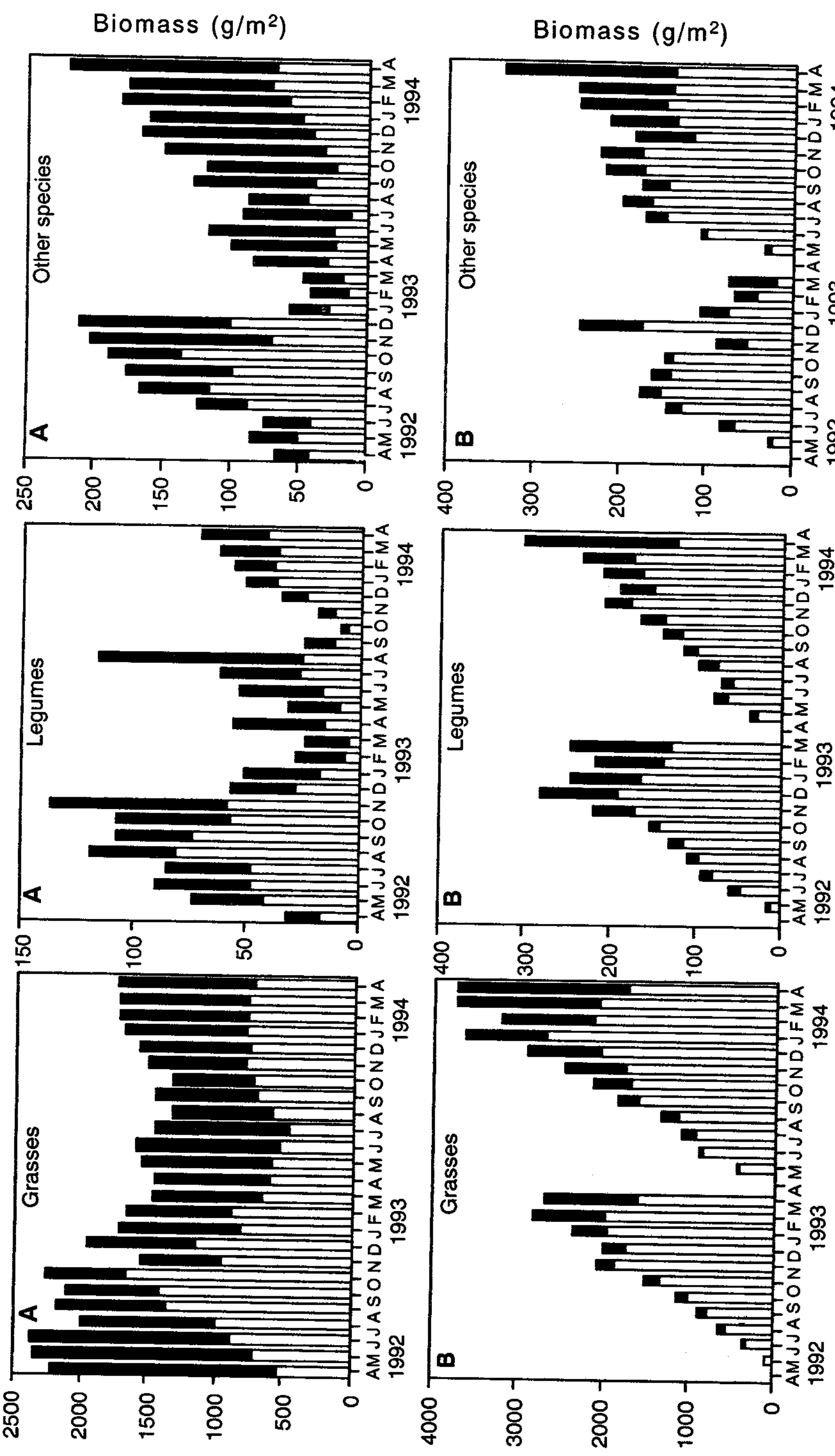

Figure 2. Mean above-ground (standing live [□] and standing dead [■]) biomass of grasses, legumes and "other species" at: (A) the unburned site; and (B) the burned site.

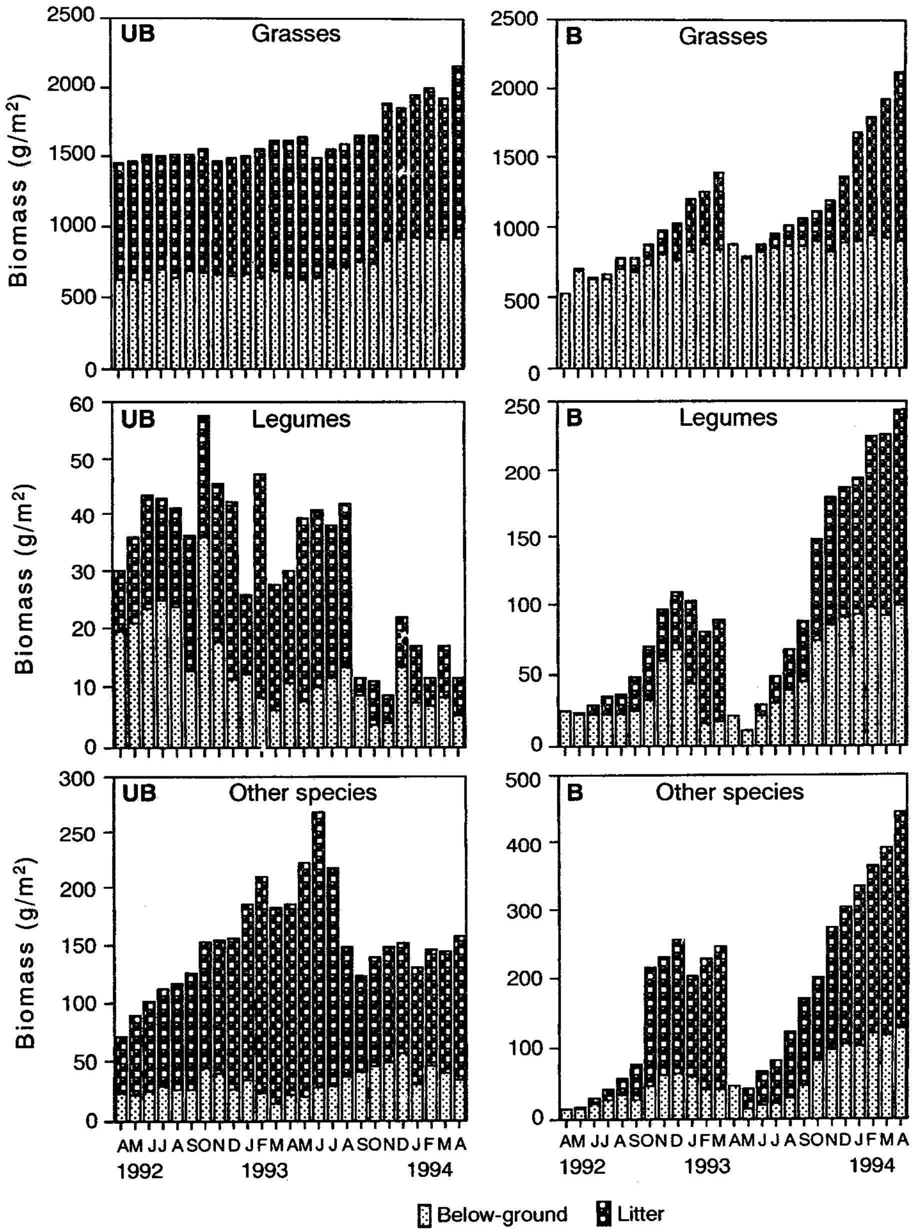

Figure 3. Mean below-ground and litter biomass of grasses, legumes and "other species" at unburned (UB) and burned (B) sites.

only 41–74% on the burned site. Other species contributed most of the remainder on the unburned site while both legumes and other species made similar contributions on the burned site.

Above-ground production

Monthly community production of the experimental sites varied between 29–673 g/m^2 (Table 2), of which grasses contributed more than 70% (values not shown). The balance was contributed equally by legumes and "other species". Burning significantly enhanced the above-ground production of the community in the second year of observation (Table 2). Table 3 gives the values for annual net production (ANP), average rate of daily production (ARP) and turnover rate and time of the experimental sites. Annual net production ranged from 1417–4857 g/m^2. Production was markedly enhanced by fire. The unburned site showed no increase in turnover rate in either year. In contrast, a considerable increase in turnover rate was observed at the burned site.

Table 2. Total production (above-ground [AG], below-ground [BG] and litter; g/m^2) at unburned (UB) and burned (B) sites.

Year and month	AG		BG		Litter		Total (AG + BG)	
	UB	B	UB	B	UB	B	UB	B
1992								
May	239	129	5	161	37	13	280	303
Jun	174	359	10	8	57	18	241	385
Jul	158	382	75	6	7	35	240	423
Aug	442	280	−72	84	45	45	487	409
Sep	86	272	−50	2	16	66	102	341
Oct	298	399	42	77	51	177	391	653
Nov	108	673	−34	119	13	23	121	815
Dec	426	169	−24	10	39	117	464	297
1993								
Jan	111	344	10	57	35	133	156	533
Feb	76	481	−30	49	128	58	204	587
Mar	40	307	46	1	22	186	107	494
Apr	135	0	12	44	39	0	186	44
May	275	505	−19	−132	97	3	372	508
Jun	127	541	20	54	36	85	184	680
Jul	11	185	79	43	−146	61	90	289
Aug	204	304	14	30	27	90	246	423
Sep	172	527	38	23	33	92	243	641
Oct	44	358	5	94	25	56	75	508
Nov	224	373	170	28	85	225	479	626
Dec	136	504	21	74	4	136	161	715
1994								
Jan	129	152	23	21	93	334	245	506
Feb	89	235	15	54	46	118	150	406
Mar	29	653	1	−19	11	186	42	838
Apr	111	523	15	19	242	282	368	824

Below-ground production

The monthly below-ground production (BGP) at the study sites (Table 2) fluctuated between 1.1–161.2 g/m^2, much of which was contributed by grasses. Generally, burning stimulated below-ground production (data not shown). However, the increases were not significant ($P>0.05$). Below-ground net production varied between 236–527 g/m^2 (Table 3). The respective turnover rates for the first and second years of study at the burned site were 0.32 and 0.41. Burning markedly enhanced turnover rate.

Litter production

Monthly litter production varied between 3.0–333.8 g/m^2 (Table 2), with the grass compartment being the major contributor. Production of litter was significantly higher at the burned than the unburned site (Table 2). Furthermore, litter production of the total community increased steadily at the burned site but not at the unburned site.

Table 3 lists the annual net production of litter, rate of production and turnover rate and time. The burned site showed greater annual net production and turnover rates than the unburned site.

Below-ground:above-ground ratio

Above-ground biomass was generally higher than below-ground biomass, with the exception of the period immediately following burning at the burned site.

System-transfer functions

The following symbols were used in the study of system-transfer functions: AGNP = above-ground net production; BGNP = below-ground net production; TNP = total net production; LP = litter production; BGD = below-ground disappearance; LD = litter disappearance; and TD = total disappearance.

The percentage transfer in different plant components at the study sites is presented in Table 4. More than 80% of total net production was transferred to above-ground net production in both unburned and burned sites. The remainder was transferred to below-ground components. The transfer from above-ground net production to

Table 3. Annual net production (ANP), average rate of production (ARP), turnover rate and time of above-ground (AG), below-ground (BG) and litter parts of grasses, legumes and "other species".

	Year	Grasses						Legumes						"Other species"					
		AG		BG		Litter		AG		BG		Litter		AG		BG		Litter	
		UB	B	UB	B	UB	B	UB	B	UB	B	UB	B	UB	B	UB	B	UB	B
ANP	1992–93	1800	3200	170	410	300	540	170	330	29	58	50	76	330	300	34	61	140	250
($g/m^2/yr$)	1993–94	1000	4000	330	230	550	1100	150	390	17	93	25	150	260	430	51	120	120	290
ARP	1992–93	4.82	8.69	0.48	1.12	0.82	1.48	0.47	0.89	0.08	0.16	0.14	0.21	0.89	0.83	0.09	0.17	0.38	0.69
($g/m^2/d$)	1993–94	2.75	11.1	0.92	0.62	1.51	3.33	0.42	1.08	0.04	0.26	0.07	0.44	0.72	1.19	0.14	0.33	0.33	0.79
Turnover rate	1992–93	0.74	1.1	0.25	1.11	0.33	0.99	1.27	1.18	0.82	1.18	1.29	1.05	1.54	1.23	0.77	1.17	0.74	1.23
	1993–94	0.58	1.1	0.36	0.25	0.44	1.11	1.31	1.3	1.26	0.95	0.8	1	1.87	1.29	0.91	0.94	0.5	0.92
Turnover time	1992–93	1.35	0.9	3.99	0.9	3.1	1	0.68	0.85	1.22	0.85	0.77	0.96	0.65	0.81	1.29	0.86	1.35	0.81
(years)	1993–94	1.74	0.9	2.76	4.08	2.24	1	0.76	0.77	0.79	1.05	1.24	1	0.84	0.77	0.43	1.06	1.99	1.09

Table 4. Percentage transfer in different plant components at the experimental sites.

Components	Unburned site		Burned site	
	1992–93	1993–94	1992–93	1993–94
TNP to AGNP[1]	91.8	84.8	79.9	93.7
TNP to BGNP	8.2	15.2	20.1	6.3
AGNP to LP	21.3	45.0	22.9	34.3
LP to LD	99.7	99.7	13.7	12.6
BGNP to BGD	99.4	99.8	97.4	99.5
TNP to TD	21.7	32.4	14.2	34.8

[1]TNP, AGNP, BGNP, LP, LD, BGD and TD, respectively, total net production, above-ground net production, below-ground net production, litter production, litter disappearance, below-ground disappearance and total disappearance.

litter ranged between 21–45%. The disappearance of litter was highly affected by fire. Only very low levels of disappearance (12–14%) were noted in the years of burning. However, the unburned site recorded more than 99% of litter disappearance. The disappearance from the below-ground net production accounted for more than 97%, but was not affected by fire. On the whole, the total disappearance from the total net primary production (AGNP+BGNP) has been put around 14–35%. The accumulation, transfer and disappearance rates of biomass of the grasses, legumes and "other species" of the study sites are illustrated in Figures 4 and 5. In these figures, the boxes with rounded corners represent the total input and output of the system while the boxes with sharp corners show the average biomass for the year. The values of transfers per day are given on the arrows. Transfer rates from total net production to the above-ground live and dead and below-ground parts were faster at the burned site. The disappearance rate of the below-ground components was also enhanced by fire. However, the reverse was true in the case of litter disappearance rate.

Discussion

The results confirmed that burning stimulated biomass production at the study site. Herbage weight is an important characteristic for range vegetation since it supports directly or indirectly all consumer groups. An understanding of the dynamics of biomass in ecosystems provides an indication of their overall functioning, and appears to be a more effective tool for planning the efficient utilisation of grasslands than the use of transient species composition (Pandey and Singh 1985).

The biomass of components of the community, *viz.* grasses, legumes and "other species", varied considerably over the period of observation. Changes in plant biomass at short intervals may be attributed to the marked changes in the climatic and edaphic conditions to which the phenology of the herbaceous species are strongly adapted and adjusted. The rainy season was characterised by luxuriant growth of almost all constituent species as indicated by their higher standing live biomass values. Britton *et al.* (1987) stressed the importance of adequate soil moisture at the time of burning to achieve higher production. In south-western New South Wales,

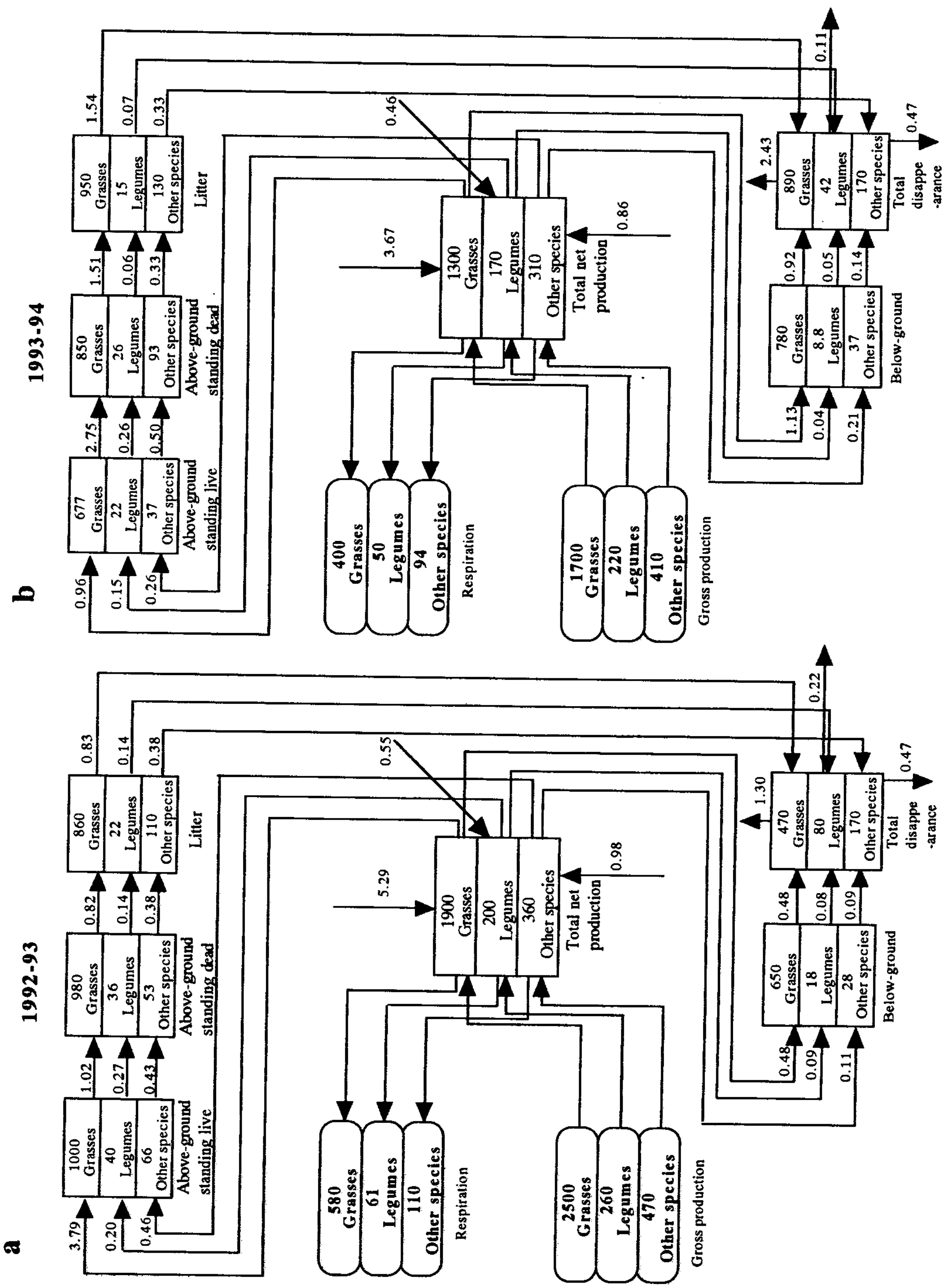

Figure 4. Flow charts showing net accumulation, transfer and disappearance rates of biomass (g/m^2) of pasture components at the unburned site in: (a) 1992–93; and (b) 1993–94.

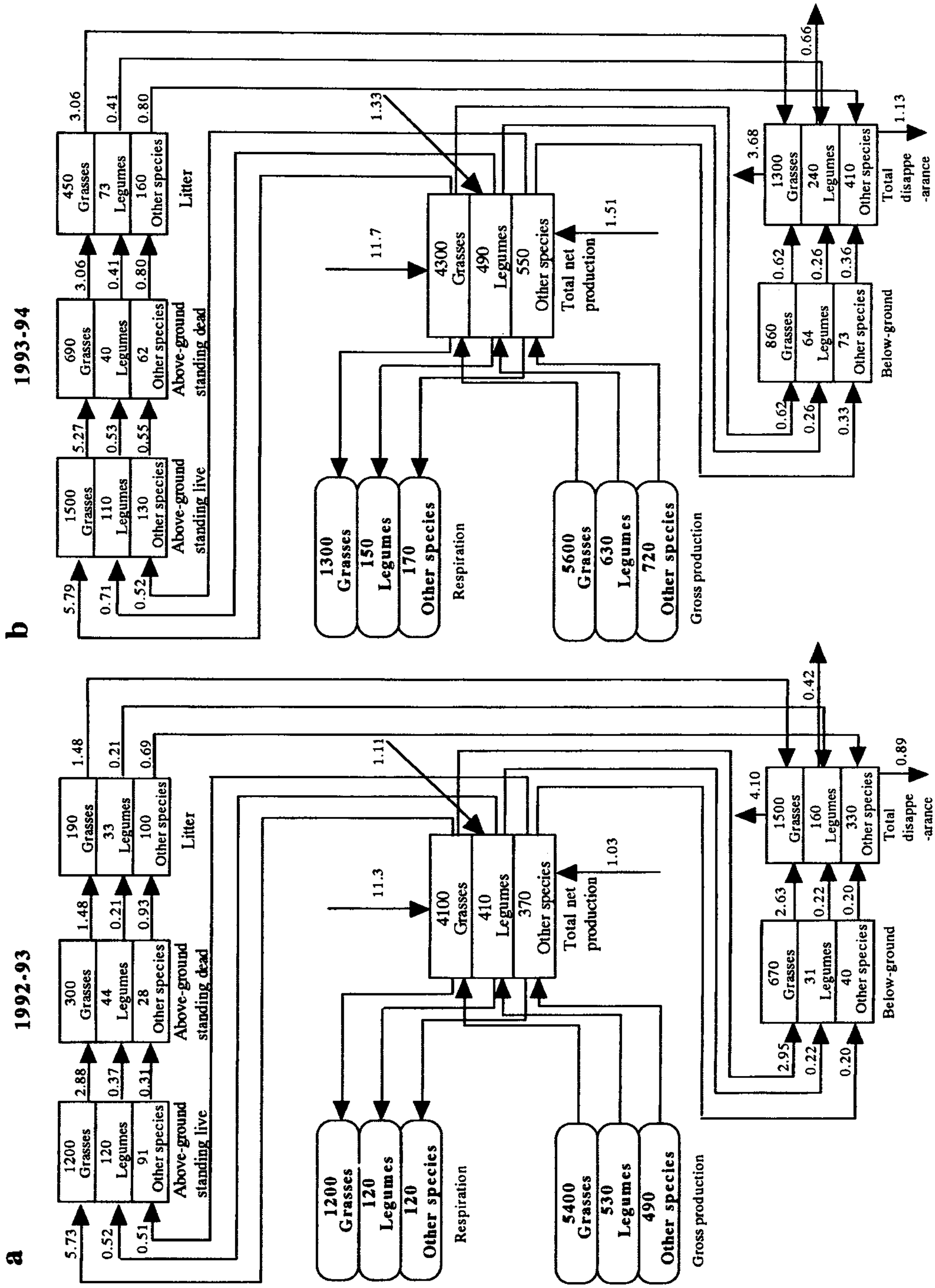

Figure 5. Flow charts showing net accumulation, transfer and disappearance rates of biomass (g/m^2) of pasture components at the burned site in: (a) 1992–93; and (b) 1993–94.

Australia, a 3-year sequence of above-average rainfall immediately following burning in either spring, autumn or winter resulted in a substantial increase in species richness and herbage dry matter production (Noble 1989). According to Tothill (1985), the decomposition of dead biomass during the dry season leads to increased NH_3, since it is too dry for nitrification to occur. At the beginning of the wet season, NH_3 gives way quickly to NO_{-3}, which is readily absorbed by growing vegetation. Gupta (1987) also reiterated that plants in the above-ground biomass were exhibited during the wet phase and minimum biomass during the hot, dry phase. When the standing dead component of the above-ground biomass in grass was considered in isolation, it made notable gains during dry months. The maximum contribution of standing dead biomass to the total community after the chief growth phase by vegetation is not new (Trivedi and Mishra 1979). However, the legumes and "other species" produced peak live biomass as well as high dead biomass during rainy months.

The below-ground biomass also registered notable increases during rainy months. This may be attributable to high above-ground production followed by downward translocation and the addition of fresh roots to the biomass during this period (Gupta 1987). The corresponding increase of root systems with the above-ground production has already been reported by Kucera (1970). Contribution of the transient species to the below-ground biomass by their appearance during this period may also account for this increase.

Burning seems to have no adverse impact on the above-ground biomass of the total community. Though it removed above-ground standing crop, this was more than made up within a year. This result could be explained in terms of the high degree of fire adaptability shown by the constituent species. Morrison *et al.* (1986) made similar observations where the peak biomass was slightly more than on the control plots 8 months after burning. On the other hand, Pandey (1988) reported less annual biomass in burned plots of *Dichanthium annulatum*-dominated grasslands of Banaras Hindu University. As the below-ground component of the biomass was hidden under soil, it was not altered by fire. The above-ground plant litter constitutes one of the basic structural and functional units of terrestrial ecosystems. In the grassland ecosystem, it can temporarily bind 40–60% of the total energy and nutrients in the above-ground plant matter (Tesarova 1975). However, burning destroyed most dead plant material at the burned site, so litter accumulation was greater at the unburned site. Likewise, Mall and Mehta (1978) and Hayashi (1989) also reported high accumulation of litter in unburned plots. The biomass of grass, forbs and litter and the relative abundance of different life-forms were highly coupled with the burning cycle. The above-ground and below-ground productivity of little bluestem grass (*Schizachyrium scoparium*) was higher on burned sites than on unburned sites (Dhillion and Anderson 1989; 1993). Harniss and Murray (1973) also reported higher production from rhizomatous grasses on burned plots than that of controls. Pandey (1988) observed growth stimulation of both shoot and root components in a *Dichanthium annulatum*-dominated grassland after burning.

The maximum contribution to the community metabolism in terms of above-ground, below-ground and litter production was made up by grass species. The above-ground net community production was markedly increased by surface fire. Similar changes in dry matter production in post-fire communities have been well documented (Pandey 1988; Noble 1989). Litter production was also higher at the burned site. This may be the direct consequence of the increased production of the standing live above-ground biomass in the burned sites which is turned later to standing dead and ultimately litter. Beneficial effects of fire on mesic tall grass prairie in Illinois last for only one growing season due to the large amount of litter which accumulates during the first year (Hadley and Kieckhefer 1963). In contrast, prairie on drymesic and dry sites tends to accumulate litter more slowly due to low productivity. Therefore, benefits of a single burn may be observed for a longer period on these sites (Anderson *et al.* 1989). It has been demonstrated repeatedly that warm-season prairie grasses (C_4) respond positively to burning (Svejcar 1990). The enhanced growth of prairie plants, especially grasses, following burning is largely attributed to increased nutrient availability (Daubenmire 1968) and favourable spring microclimate associated with litter removal on burned sites (Knapp and Seastedt 1986). Nevertheless, other studies suggest that nutrients available in ash may not be important in the stimulation of microbial and plant growth processes (Hulbert 1988).

Various reasons have been put forward for the fire-enhanced above-ground production. A number of works (Lemon 1967; Hulbert 1969; Rice and Parenti 1978) have attributed this enhanced productivity to increases in soil temperature in the burned sites. Raison (1979) also stated that increased soil temperatures may contribute to the increase in plant productivity after fire. The effect may be direct or may result indirectly from increased microbial activity and mineralisation of soil and organic matter as observed in the present study. Savage (1980), in his review on the effect of fire on the grassland microclimate, has stressed the study of microbial activity in relation to burning as a research priority. From work on the Transvaal highveld, Mes (1958) concluded that the recovery growth of 3 important grass species in burnt pastures has a higher nitrogen and mineral content than the new growth of the same species on unburnt pastures. This was attributed to earlier spring root growth resulting from increased soil temperatures where the veld had been laid bare by fire. Wright *et al.* (1976) and Sharrow and Wright (1977) found that removal of litter by burning increased the soil temperature and the rate of nitrogen mineralisation. Wright also found that ash had a slight fertilising effect but production was stimulated more by removal of litter than by any other factor.

Britton *et al.* (1987) observed that, in a tobosa grass community, burning removed old standing dead parts, which had a stimulatory effect on the current year's growth. According to Pandey (1988), the removal of the shading effect and the exponential growth of younger tillers were the factors stimulating shoot production in burnt plots. Therefore, it may be presumed that the takeover of growth function from the mature tissue by previously dormant juvenile meristems in the burned plots may account for this increased production. Old (1969) has listed the post-fire increases in soil nutrient levels as one of the important factors responsible for the enhanced production.

When grasses are associated with legumes, it results in high dry matter yield (Rhodes and Webb 1987). Comparing a pure *Brachiaria decumbens* sward with a *B. decumbens-Calopogonium mucunoides* mixture in Brazil, Cadisch *et al.* (1994) predicted a drain of soil N with pure grass pasture which could be reversed by introducing legume into the pasture. In the present study, the improvement in percentage contribution of legume to total community production at the burned site may play a central role in the increased total production. Increases in the N_2-fixing microbial population and higher nodulation (Senthilkumar 1995) at this site were already discussed.

Below-ground production is vital to sustain the community, especially during dry months. The present study revealed that below-ground production was generally promoted by fire. Decrease of rhizome production after burning was reported by Pandey (1988) and Mall and Mehta (1978) suggested that frequent burning may prove detrimental to below-ground parts. Hence, the long-term effects of regular annual burning on community production need further investigation.

Turnover is essentially the rate of rebuilding of organic matter in respect of peak biomass. Turnover rate indicates the fraction of the total amount of a substance in a component which is released in a given length of time, whereas turnover time indicates the period required to replace a quantity of substance equal to the amount in the component (Robertson 1957). The observed high turnover rates of the above-ground parts (0.7–1.23) indicate their complete replacement within a year. A relatively higher turnover rate of the above-ground components at the burned sites would ensure effective recycling of nutrients under stress. Further, the lower turnover rates for below-ground parts would ensure storage of resources and thus help in the survival of the community. Ram and Ramakrishnan (1989) also made similar observations on seral grasslands of Cherrapunji in north-eastern India.

The shorter turnover time of the above-ground components at the burned site implies higher metabolic rates in the community. The litter component was also replaced rapidly at this site. However, the turnover times of the below-ground parts were higher in the burned site thus requiring more than two years for their complete replacement.

The below-ground:above-ground biomass ratio of the community indicates that environmental conditions favoured the predominance of above-ground parts at the study site. Fire further favoured the growth of above-ground parts over the below-ground component. System-transfer functions obtained in the present investigation indicate that a large quantity of dry matter was diverted to above-ground parts. No marked differences were observed between the unburned and burned sites in the rate of transfer from above-ground to litter parts.

Transfer rates between different components were faster in response to burning. Odum (1969) observed that young communities have higher rates of transfer than mature communities. In the present study also, the fire disturbed the natural development of the community towards maturity, thus maintaining it at the seral stage. This fact is again supported by the postulation that Indian grasslands are maintained at their seral stage by various biotic factors, including fire (Singh and Krishnamurthy 1981). It is evident from the present study that fire did not adversely affect biomass production and its related aspects. In fact, fire slightly improved community production and can be used effectively as a management tool in natural grasslands.

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